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THE PSYCHOLOGY AND PHYSIOLOGY OF MIRROR-WRITING

BY

JUSTIN K. FULLER

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The research to which the following pages are devoted was begun in 1911, and was continued with several interruptions to the end of the academic year 1913.

I avail myself of this opportunity to express my thanks to the officials of the Napa State Hospital; the California Home for the Care and Training of Feeble-Minded Children, at Eldridge; the California Institution for the Deaf and Blind, at Berkeley; and to other individuals by whose courtesy I was enabled to gather much of the data for this paper. I wish to thank Professor Brown for affording me all possible facilities in the psychological laboratory, and for his kind assistance. I am under deep obligation to Professor S. S. Maxwell, of the department of physiology, for reading the manuscript. The unfailing kindness, and the constant interest in my work evinced by Professor Stratton, I shall remember always.

Berkeley, California. J. K. F.

CONTENTS

INTRODUCTION

1. Definition

Mirror-writing is characterized by a reversal of the form and arrangement of the letters, which appear as if ordinary writing were held before a mirror. It in turn becomes legible and has the appearance of ordinary writing, when seen in a mirror.

2. Conditions Hitherto Recognized as Favorable to Mirror-Writing

It will be advisable to assemble in the form of a brief resumé the various conditions under which mirror-writing has been observed. It is found as a spontaneous occurrence only in left-handed children, or in adults after right-handed paralysis, though it can be acquired by anyone after practice.*[1] It may be deliberately performed as a trick[50] or as an amusement.[12] The ability is not at all rare, and may be possessed by all persons but remain unobserved.[3] The latent ability to write mirrorwise is ordinarily made evident in adults by some lesion suddenly rendering the right arm useless. But paradoxically, nearly every child at a certain period of its development will be found to produce spontaneous, fragmentary mirror-writing with the *right* hand.[31] Children whose writing is still forming may be observed to make spontaneous fragmentary left-hand reversals, especially in the up-and-down turnings of single letters, figures, etc. Similar reversals may be seen in the left-hand writing of many adults who write usually with the right hand.[5] Left-handed mirror-writing may be a physiological sequela of weakness by disease, of weak-mindedness in children, of left-handedness, or merely of absent-mindedness in a normal person.[55] Occasionally it is seen in feeble-minded or left-handed children, or in a patient who has had right hemiplegia in early life.[47] Numerous cases have been observed to follow right-sided hemiplegia. It has been ranked as first among the manifestations of aphasia[13] and on the other hand has been supposed to have no very special connection with aphasia.[9] It has been spoken of as a congenital tendency, almost a defect, in left-handed children.[12] A neurotic inheritance may aid in its acquirement; it is met with in some forms of mental weakness, and in some conditions of mental disorder allied to the hysterical; it is more common among women than among men, and is more easily acquired by the

*The superior figures refer to the List of References, pp. 262-265.

more highly nervous people; it may occur in cases of moral perversion and may be only temporary, recurring with the other symptoms of the disorder.[67] Some mirror-writers belong to the class of learned idiots, or *idiots savants*.[8] It is more common among high-grade imbeciles than among the left-handed.[64] As a pathological condition, left-handed mirror-writing is rather common in children with impaired intelligence, in deaf mutes, the blind, and in cases of katatonia.[31] Also it has been observed in cases of dementia praecox (under which heading katatonia has been included).[54] Severe, and as a rule chronic cerebral diseases, cerebral degeneration, or feeble-mindedness may cause its appearance.[59] It may be, but is probably very rarely, indicative of nervous disease,[55] and is not in itself a sign of mental defect although it is seen in such cases.[45] Various observers have claimed for it only pathological significance, but the majority agree that it is the normal writing for the left hand.

3. A Working Explanation of Mirror-Writing

Reversed writing is produced when the hand unaccustomed to writing produces the series of motions to which the other hand is accustomed (symmetrical accompanying movements). The nervous relations whereby this unusual mode of expression is attained has long been a question of interest wherever observers have noted its occurrence. The diversity of conditions which may lead to the production of mirror-writing has undoubtedly contributed in no small part to the confusion which attaches to the subject. An indication of the variety of these conditions has been given above, and a notion of the resulting confusion may be obtained from the hypotheses of the various authors, to follow on pp. 204 ff. Although the explanation of mirror-writing is a subject of controversy, it is generally admitted that the one hand, or more generally the entire side of the body, or any part thereof, acquires skill from the practice of the opposite part. Thus, if certain groups of muscles and nerves on the right side have been

trained to perform certain definite movements (resulting in a centrifugal writing), it will be the same definite groups on the left side which have gained in efficiency. The ability to write in a centrifugal direction with the left hand is due almost entirely to this "cross-education".

4. Three Kinds of Reversal

Written symbols may be reversed as a result of at least three fundamentally different types of control. I am primarily interested in but one of these types. This may be defined as the spontaneous, automatic, unpracticed kind which in certain rare instances has been noticed to accompany or follow such conditions as are mentioned on pp. 201 ff. (except right-handed reversals by right-handed individuals or *vice versa*). The mirror-writing which occurs in all of these conditions, I have classed together, because (*a*) the mechanism for the reversed writing is similar in all these cases; (*b*) there are certain psychological aspects common to these various conditions; and (*c*) all other forms of mirror-writing are distinctly of a different order.

(*a*) The motor complex for reversed writing is a constant factor. It will be considered at length in Part III, Section 1.

(*b*) The psychological aspects, when present, remove certain inhibitions to the functioning of the reversed-writing motor complex. The inhibitory process may be likened to a brake, which when released, will allow the mechanism to glide along unhindered. The psychological factor is thus highly favorable to mirror-writing. It will be treated in Part III, Section 2. The relations of the various experiments of Part II to the reversed mechanism and to the psychological factors will be taken up in Section 3 of Part III. In this part, I will endeavor to explain the interconnection which exists in all forms of mirror-writing.

(*c*) The other forms of mirror-writing may be divided into (1) the form which results from a conscious attentive endeavor to reverse the writing; this form will be considered briefly in Part III, Section 2. (2) A kind which occurs usually only in

single letters or in fragments of a letter, and is due primarily to a confusion of the left-right relation of objects in space. This will also be considered in Part III, Section 2.

5. Summary of Explanations of Mirror-Writing Offered by Various Observers

Clapham[18] believes that abduction is the more convenient movement for writing. He studied a child who could write with the left hand almost equally well in three styles—namely, mirrorwise (the style first learned), rightwards (as she was made to write in school), and with alternate lines in opposite directions (when she was absent-minded). He sees a parallel between this case and the history of writing, which was leftwards in the earliest Greek and Etruscan period, later "ploughwise", and finally rightwards.

Wilks[69] observes that if the arms be rolled about one another, the movements are exactly alike. If the arms are extended to the sides during the continuance of the same relative movements, the right hand will trace ordinary writing, and the left hand mirror-writing. The movements and the results correspond. Hence skill in copying with the left hand the usual form of writing is acquired only after long effort to overcome the awkward use of the arm, due to the different set of muscles that are brought into play.

Wray[71] says that left-handedness must not be taken as an indication of the anatomical superiority of the right hemisphere. Our ability to write mirrorwise more easily than rightward with the left hand, rests upon the tendency to automatism of movement in an opposite direction brought about by the movements of the hands in opposite directions while walking.

List[47] simply notes that mirror-writers use the left hand; hence the natural result is to write from right to left.

Durand[21] observed that among intelligent persons mirror-writing with either hand is difficult, because of the very strong habit of writing from left to right; but that in the unintelligent

there is an aptitude to write either style with the left hand. The image of normal writing being less strong in the latter case, the inclination is largely unhampered by it.

Grace Peckham[55] reasons, *a priori,* that mirror-writing may indicate a change in the perception of the nerve centres of the brain. But if this were so, the patient should read this form of writing more easily than the normal, a condition she has been unable to verify, with possibly one exception, in the literature. She therefore attributes mirror-writing in every case to a mechanical cause, the person finding it easier to write in a centrifugal direction: the "association of ideas and muscular action making this so." The reason lies in a physiological, not a pathological, condition; therefore anyone, when not exercising care and forethought, might be expected to write in a reversed direction with the left hand. Similarly the so-called "pathological" cases of mirror-writing are probably brought about through weakness by disease, weak-mindedness in children, or simply as a result of left-handedness.

Erlenmeyer[23] believed abduction to be the natural method for executing all finer movements. His corollary to this is that writing toward the right is a result of right-handedness, and the greater development of the left cerebral hemisphere is the result of right-handedness, not its cause. Consequently those who wrote from right to left must have been left-handed, for the right hand follows the general tendency of abduction.

Ireland,[38] while he admits that most actions requiring skill are more easily executed in a centrifugal direction, yet criticizes Erlenmeyer's illustrations. For instance, Ireland has seen quite as brilliant passages on the piano done in a centripetal as in a centrifugal manner. This is also true of many other delicate operations, such as using the sling, bowling and batting in cricket, fencing, swimming, sewing, and so on. Ireland[35 38] has shown by a number of experiments and observations that there is a physiological tendency for left-handed children to write mirrorwise. This tendency occasionally prevails in adults who for some reason use the left hand. As an instance, some Arabic

characters were unconsciously reversed by the left hand of a subject. Hemiplegia of the right side is also an important factor in bringing about left-handed reversals. His general conclusion is a modification of Erlenmeyer's theory, with the additional idea that two mental images are formed, one on each hemisphere of the brain. The image on the right is the exact mirror-reverse of the one on the left, so that the left-handed writer would trace) for (.

Kingman[42] cites several tests to illustrate the old idea that abduction movements are the more natural and graceful for either hand. He also supposes that "analogous pictures reversely formed" are developed in the right brain conjointly with those in the left in two ways: (1) to some extent co-ordinately; (2) by what may be termed an overflow process, occurring either concurrently or because the left centers have attained a maximum degree of development or training. Further, the conclusion is that the image on the left cortex may be "called into play with either left or right hand to produce ordinary writing", and the converse. However, writing from left to right with the left hand is as unnatural as mirror-writing with the right hand, which explains why mirror-writing is most frequently seen in those who are not up to the standard of the normal educated man. The latter is able to make the transposition of graphic memory at will, and consequently write either form with either hand. And "both of these graphic picture centres may also be correlated with the appropriate muscle motor centres to produce mirror or ordinary writing through the medium of the toes, lips, elbows, or any other part to which suitable apparatus can be attached."

Leichtenstern[45] assumes that the left hand receives its stimulus from the right cortex, and following its natural desire for abduction movement, produces mirror-writing. He speaks of a "peculiar opposition" found in the left hand to writing rightwards, thus making mirror-writing the easier form in all cases.

Acker[1] agrees that writing is more easily formed in a centrifugal direction. Also that mirror-writing has followed dis-

ease of the left side of the brain in numerous recorded cases. He states that there is a physiological tendency for left-handed children to fall into mirror-writing.

Buchanan[12] cites certain cases which "point with some clearness to the fact that the person who is using the right side of the brain . . . has a very strong tendency to write mirror-wise; and we may assume that in the case of the left-handed person the right side of the brain is so used." The author believes with Erlenmeyer that there is a greater natural tendency towards abduction than towards adduction.

Mills[50] holds that "special convolutions in the right hemisphere have in a quiescent and undeveloped state the same functions which are active in the corresponding convolutions of the left hemisphere." Impressions received by the left cortex of a normal person are recognized as normal or usual images, and as being right side up. The images formed on the right cortex are usually suppressed. When these parts of the left cortex are injured, their functions are re-acquired through the arousing and developing of the latent activities of the right hemisphere. For those cases of mirror-writing occurring in the absence of direct lesion of the left cortex (e. g., injury to right arm), he assumes that the development of the left cortex is arrested and the individual is guided by the images on the right cortex. Similarly, mere use of the left arm may cause the images of the right cortex to be aroused sufficiently to guide the arm. A possible explanation for some isolated cases of left-handed reversals may be that the individual can write with readiness in the centrifugal direction.

Bastian[9] thinks mirror-writing has no very special connection with aphasia. He believes that a centre for writing movements may be developed in either hemisphere for writing with the opposite hand. He criticises Elder's belief that there exists but one special centre, located in the left brain: for if this were so, how would one account for the fact that only five per cent of the subjects tested by Elder were mirror-writers?* Bastian

*See p. 210.

inclines to the view that "writing movements of the left hand are controlled by the conjoint activity of visual and kinesthetic centres in the right hemisphere, just as the writing movements of the right hand are controlled or co-ordinated by similar centres in the left cerebral hemisphere."

Bruce[11] deduces from his study of a case of dissociated personality, in which "the right and left brain alternately exert a preponderating influence over the motor functions", the separate control of the sides of the body each by the opposite cortex. Mirror-writing was the usual form when the patient was in the left-handed stage.

Auden[4] believes "that there are potential kinesthetic centres for writing on each side of the brain." For left-handed rightward writing the impulses from the motor centre which co-ordinate the movements of the left hand are "reinforced and overlaid by a train of motor-memory impulses from the cells of the cheiro-kinesthetic centre for the right hand." For this reason mirror-writing is generally found in young children and is usually transitory, disappearing as the right hand becomes more facile in the use of the pen.

Peretti[57] supposes a dual brain action similar to that assumed by Ireland. He believes that mirror-writing in hemiplegia is due to the mental obtuseness of the patient, rendering him like a young child. He says that a woman hypnotized on the left side of the body, which he assumes implicates only the right hemisphere, traced mirror-writing with the right hand: and when hypnotized on the right side of the body, she wrote with the left hand towards the right.

Bianchi[10] notes that a characteristic of ordinary writing is that every people uses the right hand, no matter in what direction the characters are traced; and that the "psycho-mechanical" act of writing is executed by a reflex mechanism similar to that of oral speech, the sensation coming for the most part through the organs of sight, and to a lesser degree through the "auditive" sense. He thinks it impossible that the seat for the disposition of the words and the impression of the motions

necessary for their formation, and the impression of the image of the words, should be only in the left hemisphere. By their presence in the right hemisphere, even to a much slighter degree, he accounts for the cause of both the pathological (hemiplegic) and the more normal form of mirror-writing. He says:

> In a hemiplegia of the right side it will therefore happen that the image, not calling forth, on the left hemisphere, any centrifugal motion in the muscles on the right hand, will oblige the extensor cellular groups in the sound right hemisphere to write from the left, because of the preserved remembrance of the muscular combinations associated with the image of the word.

Hence, there will be an identical centrifugal motion giving lithographic writing. If one writes centripetally with the left hand, the muscle groups are antagonists to the muscle groups used in right-hand ordinary writing, and thus give an "insupportable contraction."

Burr and Crow[14] think that associated movements are due to bilateral representation in the cerebral motor cortex of the parts affected, plus motor overflow. Thus, these movements result if an adult has not learned to restrict completely the random movements of the infant. Mirror-writing, depending upon these principles, offers a less complex problem than the wider question of associated movements in general. Simultaneous writing with the two hands is not naturally identical, but opposed. In this fashion, the ordinary educated man will write rightwards with the left hand only if he "uses his will to make himself do so", and the real reason imbeciles write mirrorwise with the left hand is not that they are imbeciles, but because being imbeciles they "permit the left hand to do what it will without trying to control it."

Rudolf[60] thinks that we get a double image in the visual centres, the one in the right side being the reverse of the one in the left. The impression in the right cortex of ordinary people is so poor, however, that it is not used for left-handed writing. Instead, ordinary writing is slowly traced out. But in a naturally left-handed person the impression on the right brain is

good, and therefore mirror-writing is the natural type for the left hand. Moreover, it would result that all persons showing right hemiplegia with mirror-writing are either left-handed or ambidextrous.

Campbell[16] is not convinced that writing is exclusively the function of one hand, although in writing "forwards" with the left hand the movements do not correspond to the usual right-handed movements; yet one may learn this form quite easily, and it does not seem that there are many disadvantages attached to such an accomplishment.

Elder[22] differs from the view that there are two writing centres. He tested 451 persons of different ages and sexes and found that 5.1 per cent, when first bidden to write with the left hand, reversed their script. He finds that the left-handed mirror-writing agrees in every detail with the usual right-handed writing, and therefore must be guided by the same centre. This centre could not be the visual centre, else the writing would be in the usual shape and not mirrorwise.

Allen's[3] conclusion is that the true graphic center is not coincident with either of the motor centers, but superior to them all. Thus he suggests that all the messages start from the same region of the brain. But at a lower level they are turned into different channels leading to analogous but sometimes heteronymous groups of muscles.

Russell[61] agrees with the theories of Allen and Elder, although, in the case he observed, the mirror-writing was very faulty and bore no resemblance to the normal right-handed writing of the patient. The single cortical centre should innervate homologous muscles, making the resulting left-handed mirror-writing perfectly normal. He intimates that the fibres connecting Broca's convolution with the lower centres are damaged, rather than the special centre itself. In addition, the frequency of occurrence of mirror-writing in aphasia "suggests that there may possibly be some special connection between the two conditions."

Jones,[40] although hazarding no explanation for the occur-

rence of mirror-writing, gives a rather good destructive criticism of some of the existing views. The only explanation which seems to him at all adequate, is that given by Mills in the *Encyclopedia Medica.* As most mirror-writing is left-handed, the movements are primarily guided by the left cerebral cortex through some preponderating influence which the cells on the left side have over those on the right. As a result the movements of the left hand are symmetrical with those of the right, and because the same relative muscle-groups on the two sides are used, mirror-writing will be the left-handed type. Some stress is placed upon the particularly close association of the two hemispheres through the corpus callosum. Even this explanation, says Jones, affords but little light on the subject. He is especially bitter towards the "retinal-image" and "mental-image" hypotheses. He remarks that the blind suddenly given vision do not interpret it as inverted.

Smith[63] notes that the various idiosyncrasies of right-handed writing will be copied in reverse by the left, but that these peculiarities will not be followed if the right hand writes in reverse. He is not able to decide whether this phenomenon is due to more or less facility of hand movement (as suggested by Erlenmeyer) or whether it lies deeper, in some unilateral brain perception.

A view having great divergence from previous hypotheses was offered by Hale and Kuh.[31] These authors formulate a theory, based upon the relation of objects in space to the complicated process of mental co-ordination. They call attention to the fact that right-handed fragmentary reversals are of far more frequent occurrence than left-handed mirror-writing; an observation which, if it had been made, was hitherto considered of little or no importance. Only by laboriously acquired experience do we learn to interpret the inverted image on the retina and produce an upright writing. The child and the feeble-minded, lacking this experience, or the adult suddenly deprived of it, reproduces the visual image in incorrect spatial relation; hence the mirrored or completely inverted writing.

Complete inversions are, however, rare; as the lateral relationship, being the last and hardest to acquire, is first to be lost. They claim that the link which unites all the various states in which mirror-writing shows itself is an imperfectly developed (in the very young or in some mental deficients) or pathologically disturbed (after hemiplegia and in certain acquired psychic disturbances) psychic association and co-ordination. But little credence is placed in the "abduction" theory of Erlenmeyer as an explanation for mirror-writing, because if this movement were a very powerful stimulus, mirror-writing in right hemiplegics would be the rule rather than the exception. The criticism of Ireland's theory is that modern physiological psychology cannot accept with such completeness the dual character of the brain; nor does this theory cover all cases.

Sweeney[64] attributes mirror-writing to a disarrangement of sensory impressions, with a resulting confusion or suppression of one or more of the factors which give us our idea of the spatial position of objects. Thus, a case of astigmatism may so interfere with the muscle sense as to prevent the proper association in the mind with other sensations and a normal transposition of the retinal image. Mirror-writing in such a case was completely eradicated by glasses that removed the reflex stimulation. The reason why mirror-writing is reversed, and not inverted, is that the lateral visual field is more extensive, and muscular movements are more frequent in a lateral direction and hence more easy and unconscious; the impressions conveyed to the mind are less in degree than are the vertical; the latter is a more purposive stimulus, and impressions conveyed by the muscular sense are less likely to be overpowered by the reflexes excited by eye-defects. The disarrangement in hemiplegia "may be that the unaccustomed use of the other hand for writing, and the confusion between former muscular habit, memory and the effort to adapt new centres to an unusual task would produce a reversal of writing when attention is not directed to the formation of words." The author criticizes Ireland's assumption of a corresponding but reversed image in the right brain of right-

handed individuals, as a "rather violent hypothesis", and asks why, if this be so, there is not inverted vision as well as hemianopsia when the visual centre of the left hemisphere is destroyed —a condition which does not exist. Also, he claims it harzardous to explain mirror-writing on the basis of mechanical ease, as Peckham does; for, if so, at least a tendency to mirror-writing should be shown by all left-handed individuals beginning to write, and not by a small percentage only.

Pendred[56] inclines to the view that "the pictures of letters in the boy's [referring to the case of spontaneous mirror-writing he is studying] memory centre are incorrectly stored and incorrectly reproduced." He thinks that the receptive apparatus in the occipital lobes may "play this strange prank with the naturally inverted pictures of letters received on the boy's retina." He notes "that the letters are not inverted, as would be the case if the brain merely failed to right the retinal images."

With regard to the sort of control utilized by subjects voluntarily writing reversedly, Abt[2] distinguishes three classes: (1) Those who before writing represented the form of letters as reversed—to which but three of his thirty subjects conformed. This method was found to be slow and laborious, the writer was apt to become confused and there was frequent reversion to rightward writing. (2) Those who depended upon visual representation of the symmetrical movement. This was the usual method of control. Mistakes were rarely errors of reversion to rightward writing and never of partial reversion of a letter. (3) Those for whom, apparently, the auditory motor image immediately evoked the movement. The existence of this control Abt questions, for if the auditory motor image calls forth left-hand mirror-writing, how can it call forth by the same mechanism right-hand mirror-writing?

Downey[20] questions the possibility of classing six of her eight subjects (two used Abt's first method, modified) under Abt's second heading; she says: "For why may there not be a motor as well as a visual representation of a movement?"

Visual representation of a movement was rarely spoken of, but grapho-motor control was frequently insisted upon, sometimes as a matter of anticipatory imagery. Downey accepts the possibility of a purely motor representation of the movement.

6. Classification of Previous Theories

The theories of mirror-writing may be divided into six groups, viz.:

(A) The explanations which depend upon the facility of external motions of the limbs.

Advanced by Durand, 1881–2; Peckham, 1886; Clapham, 1894–5; List, 1901; Wilks, 1902; Wray, 1903.

(B) Those which place emphasis upon the facility of centrifugal motions of the limbs, but in addition attribute the ultimate causation of specific movements to bilateral representation on the cerebral cortices.

Advanced by Erlenmeyer, 1879; Ireland, 1881–1893; Leichtenstern, 1892; Acker, 1894; Mills, 1894; Kingman, 1905; Buchanan, 1908.

(C) Those hypotheses based primarily upon bilateral representation on the cerebral cortices. This group is closely allied to group B.

Advanced by Peretti, 1882; Bianchi, 1883; Bruce, 1895; Bastian, 1898; Campbell, 1903; Rudolf, 1903; Auden, 1909; Burr and Crow, 1913.

(D) Those that admit but a single writing centre.

Advanced by Smith, 1879; Allen, 1896; Elder, 1897; Russell, 1900; Jones, 1903.

(E) Those that depend upon disturbance of vision or of the visual centre.

Advanced by Sweeney, 1900; Hale and Kuh, 1901; Pendred, 1908.

(F) Those which recognize various controlling factors for

individual voluntary reversals. Thus the movements may depend upon motor, visual, mental or auditory-motor imagery.

Advanced by Abt, 1901; Downey, 1908.

A closer examination of the relative value of these groups, as well as any criticism of them, may be best postponed until my own experiments and observations have been given.

PART II

EXPERIMENTAL FINDINGS

I have arranged the following account of my own experiments to conform in a general way to the degree in which the conditions favored the production of mirror-writing. A fuller description of the relation of these conditions to mirror-writing will be found toward the end of Part III.

1. Hypnosis (4 subjects)

These subjects were normal, but were tested when in the deeper stages of hypnotic sleep.

Subject A. Twenty-nine trials writing single simple words with the left hand. Of these words, twenty-four were entirely reversed. Thirty-four trials, single letters, twenty-eight were entirely reversed. Of the six that were not completely reversed, five were partially reversed.

Subject B. Thirty-one trials with words, seven trials with sentences, thirty-nine trials with letters. Each and every one was reversed. The subject showed no hesitation whatever; the reversals were easily and rapidly written. During this test, the subject was hypnotized four separate times, at periods of from one to two weeks apart, and each time produced mirror-writing post-hypnotically as well as while hypnotized. According to her statement, she has never been inclined to left-handedness. She was unable to decipher the writing, unless by the usual means of retracing each separate letter. After the four tests, I explained the matter of mirror-writing to her. Then,

using a planchette, I desired the subject to devote her entire attention to the problem of mirror-writing.* The result was a slow, hesitating, poorly executed form of reversal, typical of what will later be described as attentive mirror-writing.† I then carried the subject through successive stages of distraction of the attention from the left hand, and of dissociation of the mental from the motor functions, until she arrived at that stage of abstraction so nearly allied to hypnosis that the mirror-writing was automatic and complete. In each successive stage, the automatic character of the reversed writing showed a corresponding increase. As an example: the subject tapped with her right hand with the greatest possible rapidity on a telegraph key, at the same time that she said the alphabet backwards and wrote words with the left hand. Several words would be written in a rightward direction, then one or two or three would be reversed directly back over the words just written. No hesitation occurred between the two styles, and the reversed writing was quite as rapid and was better executed.

Subject C responded in only a slightly less degree than did subject B.

Subject D. None of forty words was reversed. By using various suggestions to the effect that the automatic and attentive apparatus should be dissociated, I succeeded in gaining a complete mirror style from the reagent's left hand; after this the subject was just as amenable to the different tests as was subject B.

2. Hysteria (1 subject)

Accompanying the other symptoms of the disease, there was complete anesthesia of the left side of the body—shoulder, arm, and pectoral region. I placed her left arm on the planchette

*The planchette, on a large piece of paper, I found most useful in many tests. A minimal amount of attention need be directed to holding the pencil, and to its position on the sheet; moreover, muscular weariness in prolonged tests is reduced. The result is that muscular responses to feeble stimuli are much more marked.

†See p. 241.

but obtained no response. Upon suggestion that it was the right arm which rested on the planchette, and that she could write just as well with the left arm, etc., I finally succeeded in getting writing from the left arm, though the patient was unaware of the movement of the arm. The writing was entirely mirror-fashion.

3. Drugs (25 subjects)

I thought that, by the use of drugs, I might simulate to some extent the conditions which are most favorable to mirror-writing with the left hand.

a. Alcohol (18 subjects)*

The first portion of the test was the same in every case. It consisted in holding the patient's right arm, and forcing him to write, or to make the motions of writing, with the left. The process was accomplished as quickly as possible, giving the patient very little time to collect his wits or to plan his motions. Ten trials were taken with an interval of two minutes between each. One subject, E, deeply influenced by the drug, wrote letters, words, and entire lines in mirror-writing.

Four patients were in a comatose condition and were examined immediately upon revival by aromatic spirits of ammonia. Two of them, F and G, indicated that they would write (i. e., made definite writing motions, which could not be recorded owing to the conditions of the tests) exclusively in a reversed direction; one (H) indicated a reversed direction in about fifty per cent of his movements; and another (I) showed no tendency to reversal, aside from the purely random nature of many of his motions.

The remaining thirteen reagents were less completely under the influence of alcohol. Eight of these (grouped as J) evinced considerable doubt and usually showed a tendency to stop and figure the thing out. Prodded on to the attempt, they often

*The alcohol was not administered for these experiments. Subjects were found in various localities and were tested on the spot.

showed impatience and dashed off their word now rightward and again leftward. The greater the anger and haste evinced, the more likely was the writing to be reversed. The other five (grouped as K), though well intoxicated, were less so than group J. They showed very little tendency to reverse their writing, and then only when they could be forced to write immediately after the signal was given.

The second part of the experiments with alcoholics was subject to much variation, as one plan or another suggested itself and was tried out. Thus, suggestion in one form or another was tried in each case. By this means the percentage of reversals was increased, especially in the relatively less intoxicated stages. Two of group J and one of group K became so adept, with a little instruction, that it seemed quite impossible for them to write rightward.

b. Cannabis Indica (3 subjects)

Subject L (myself). In 122 trials at writing words, seventy-two per cent were completely reversed. In 240 trials at writing individual letters, the letters were completely reversed, or hesitation was shown as to how to begin the letter, or the letter was reversed in part, in eighty-one per cent of the cases.

Subject M. Of eighty-one trials at writing words eighty-four per cent were completely reversed. Of 106 trials at writing individual letters, the letters were completely reversed in sixty-six per cent of the trials; hesitation was shown as to beginning the letter in six per cent of the trials; and the letter was reversed in part in three per cent of the trials.

Subject N. In ninety-six trials at writing words, two per cent of the words were completely reversed. Of 145 trials at writing individual letters, three per cent were completely reversed; hesitation and confusion were shown in twenty-nine per cent of the trials; and the letter was fragmentarily reversed in thirteen per cent of the trials.

A few trials at right-handed writing were given in each case

before the left-hand tests were started. In no case was there any indication of reversal.

As usual, after the regular tests were finished, variations were added in the attempt to locate some definite factor which would either favor or retard the production of mirror-writing. Here, as before, suggestion was found to be most potent. Conversely, merely to point out to the subject the queer appearance of his reversed script was enough to stop altogether, for the time being, its production.

c. Ether (4 subjects)

The trials are necessarily few in number because of the very short duration of the stage of intoxication which I found by testing other patients to be most favorable to mirror-writing. This is during the recovery of the patient, but before he is conscious. The giving of the drug was, of course, not in my hands, as the patients were being anaesthetized for minor operations. Usually the patient merely indicated, by a jerky sweep of the arm, the direction of his writing. With the right arm, this direction was always rightward; with the left arm:

Subject O. Eight trials, words all reversed.

In twelve trials in which I attempted to make the subject realize his error, ninety-two per cent of his movements were reversed; that is, this patient could not be made to realize that he was writing in any but the normal manner. Later stages in his recovery were not satisfactory, as he was quite conscious.

Subject P made no reversals.

Subject Q hesitated before each motion, and only in two of eleven trials did he reverse. Single letters were not reversed in nine trials. In seven of thirteen trials he was induced to reverse words or letters by suggestions to that effect.

Subject R reversed in four of nine trials with words; in six of eleven trials with letters, the other five trials showing doubt and no motions of a decisive nature. Suggestion in nine trials produced no noticeable increase in the reversals.

4. Abstraction (15 subjects)

The persons experimented upon were in normal life, ten belonging to no particular class, while five were engineering students. Different methods of inducing abstraction were employed; for instance, mental arithmetic, crystal-gazing, and so on. In half the trials the reagent kept in his left hand a pencil held on paper in position to write; and in an equal number of tests he rested his left hand on a planchette. Immediately upon a signal, he was to begin a word. I found that only the first line was of any value, for almost as soon as they began to write, they awoke from their abstraction, and summoned attention to their aid in finishing the word. The first stroke was started mirrorwise in some thirty per cent of the ninety trials I deemed it fair to accept as answering all the conditions of the test.

5. Insane (5 patients)

These patients were confined in an institution, and no hope was felt with regard to their recovery. Unfortunately, the diagnoses of the particular types of disorder they suffered from were not satisfactorily determined for inclusion in this article.

Subject S retained just enough intelligence to write a few words. He looked at me when writing, and not at the script. With the left hand, mirror-writing was formed without exception.

The other four patients wrote mirrorwise from fourteen to seventeen per cent in some eighty-five trials each, given at intervals of several days. Hesitation was shown in starting a letter in about twenty-three per cent of eighty trials each.

6. Hemiplegia (right side paralyzed, 2 insane patients)

Subject T could not be induced to write in anything but a reversed direction. His general mental condition was so poor that he could remember only a few letters.

The other patient was in better condition mentally. He

produced mirror-writing in but nine per cent of 116 trials. By suggestion, I could raise this percentage only to 11 per cent. Of 118 trials with individual letters, eight per cent were entirely mirrorwise, ten per cent showed some hesitation or fragmentary reversals. That is, there was comparatively little hesitation; the letter was either reversed or it was not.

7. Feeble-Minded (69 patients)

Of these, twenty-six were in the intermediate grade (second reader) of school. Asked to write their names with the left hand, only two produced mirror-writing. Directed to write a double word, such as "Glen Ellen", with the left hand, but to turn the paper through an angle of 180° in its own plane, between the two words, I found that six wrote "Ellen" in mirror-writing, including the two above, who wrote "Glen" mirrorwise as well. Eighteen of the twenty-six showed, in all the tests, marked confusion in starting; the line now being started mirrorwise, and then in its usual direction. When I wrote mirrorwise the word "California", but three of the patients had the slightest difficulty in copying the word reversed.

Of twenty-three patients in the advanced grade of the school, studying geography, etc., but one wrote mirrorwise with the left hand. Testing as above with the words "Glen Ellen", but three reversed "Ellen". Less confusion than in the first group was shown in starting a letter with the left hand.

Twenty other patients—nine children, eleven adults—were tested; these were of low grade, and not in the school, although they could write a few words or letters. One half were chosen on account of a marked neurotic history; the other half were as free from anything but pure "feeble-mindedness" as I could find. Of the first ten, six proved to be mirror-writers, two of the remaining four could be confused into mirror-writing, while the other two could not be induced to write mirrorwise at all. Of the last ten, but one wrote mirrorwise, only two could be confused, but all of them could copy, in reverse, words written in mirror style.

In examining the histories of the forty-nine school patients, I found that with three exceptions, every patient who had shown a tendency to mirror-writing had a neurotic taint other than feeble-mindedness. Thus, one had epilepsy; another, a hysterical mother; another, an insane father; and so on. Of the remaining patients, one-fifth gave a similar history, the rest being classified as merely "feeble-minded" or retarded. The neurotic tendency would lead to mental confusion, whereas the feeble-mindedness would place the patient in the same class as young normal children. This, as will be seen later, is an important point in the problem of mirror-writing.

8. Deaf and Dumb (77 patients)*

Of forty-two in the upper grades in the school examined, but two wrote mirrorwise with the left hand. Twelve of this number, exclusive of the two above, wrote the second word mirrorwise upon turning the paper through an angle of 180° in its own plane. Thirty-five showed great readiness in copying words after I had written them mirrorwise.

Of thirty-five deaf and dumb children in the lower grades, none showed the slightest desire to reverse letters or words. After a few trials, some of the children could be confused on such letters as *S* and *N*. When asked to copy words written mirror-fashion, the majority were able to do so, but a few began at the left and copied rightward.

9. Blind (5 subjects)

I was inclined to doubt Soltmann's figures for the deaf and dumb, but thought they might agree more nearly with the left-hand writing of the blind. Unfortunately for my purpose, blind children are no longer taught to write long-hand, and I could find in the institution I visited but five children who could

*These tests on the deaf and dumb were made to verify a statement of Soltmann, quoted by Gould [28] p. 106 that of seventy-seven deaf mutes, thirty-five per cent wrote mirror-style with the left hand.

write. None of these evinced the slightest inclination to spontaneous left-hand reversals; nor could they be readily made to understand the usual explanation of mirror-writing, or to reverse their script. It should be understood that none of these five children was congenitally blind; with the congenitally blind a different set of factors might be operative, making left-handed reversals easier.

10. Normal Children (26 subjects)

First type, eighteen children who had just learned their letters. In no case, by any of the ordinary means, could I get any of these children to reverse their words, or even the letters, except that in rare instances they reversed such confusing letters as *S* and *N*. Often there was hesitation, but nearly always the correctly formed letters were written.

Eight children, a grade ahead of the first type, frequently reversed certain confusing letters and figures with the left hand. By employing various means to confuse them, this percentage could be considerably increased, and in one instance I succeeded, without suggestion, in getting several words in mirror-style.

11. Persons with Special Training of the Arms

Thinking that a person's occupation or his training in writing would have some bearing on the readiness with which the motions of the left hand would be reversed, I tried a number of tests, among which the following had the most instructive results. In the first part of each of these tests, nothing was explained to the reagents, who were merely asked to write the same things on a black-board, simultaneously with both hands, and centering the attention on the right hand.

a. Clerks (12 subjects)

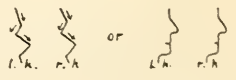
Analogous accompanying movements based on the visual or mental significance of the symbols was best illustrated by twelve clerks, highly trained in writing. With the left hand, the writ-

ing direction was always rightward; no indication of reversals in fifty-eight trials. When the same reagents were urged to rapidity, one subject fragmentarily reversed three letters in thirty-two trials.

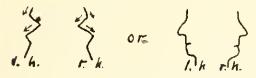
I carefully instructed them in the trick of mirror-writing. If given plenty of time, they could reverse the characters with the left hand, but if urged to speed, in almost every instance they wrote rightward with the left hand. After some twenty trials, three of the reagents thought the mirror form the easier. But when I asked these three to write mirror-fashion with only the left hand active, they were in each case lost. They hesitated, made two or three false starts, and finally produced a reversed script that was very much poorer and more labored than when both hands were active. Asked why this was so, each one told essentially the same story; that he thought first how the motions of forming the ordinary letter would look, while at the same time, or a little later in the case of simpler letters, the hand was engaged in moving in just the opposite direction. Sometimes, with certain letters, the first step seemed unnecessary, whereas, when both hands were active, little or no attention was given to the left hand. The other nine, after considerably more practice, arrived at the same conclusion.

b. Plasterers (12 subjects)

Analogous accompanying movements based on motor habit was best illustrated by twelve plasterers—whose trade requires that both hands make similar movements simultaneously. They drew on a black-board any figures that occurred to them, also copied several figures more or less meaningless, and followed the motion I made when drawing other figures. As usual the subject was at first unaware of the purpose of the request. In all cases the left gave a correct imitation of the right hand, i. e., the figures were:



Subjected to the same tests as the clerks, they were more

backward in learning, probably because they had less imagination. On the other hand, the clerks and students found it much easier to draw arbitrary figures similarly related, i. e.,  than did the plasterers, after this problem had been set them. In fact, several of the students drew figures in both relations before any definite direction had been given.

12. University Students (31 subjects)

Merely asked to write simultaneously with both hands, they gave no indication of mirror-writing. I now told them imperfectly what might be expected, merely giving them a hint; I then asked them to close their eyes, and to write *rapidly* with both hands. Six showed a rather strong tendency to reverse the left-hand figures. It is significant that all of them reversed a few lines, mostly the first strokes of the figures. About a dozen trials each were given. Furthermore, this ratio more than doubled when the reagent was placed in a condition of abstraction (mental problem, etc.) When I finally explained that it was easy to reverse the left-hand script, every subject found this so, after a couple of trials. They also found it much easier to reverse the left-hand script when the right hand was passive, than did the clerks. They found, with a little practice, that it was much easier to reverse with the left than with the right hand, each being used separately.

I noted in all the above reagents that if both hands are active, the left-hand figures are much more cramped, are less freely executed and less pleasing to the eye when drawn in a rightward direction than when reversed. Again, after the reagents were well practiced, as a rule they found it easy to write mirror-writing with the right hand, when attending to the left hand, which wrote rightward. Any peculiarity of the strokes, or their relation to one another such as is apt to occur when we use the left hand for writing, will be observed in reverse in the writing by the right hand.

13. Reversed Visual Field (16 students)

I employed a right-angled prism with broad faces, which by means of straps could be adjusted comfortably before one of the subject's eyes, the other being blindfolded by a curtain dropped from the front of the gear.

Sixty-four trials at writing with the right hand produced no evidence of reversals. Sixty-eight trials at writing with left hand—rightward direction in eighty-seven per cent; and scratches, i. e., starting lines in one direction or another, and as soon discontinuing them, confusion, and inability to produce anything like rightward or reversed writing, in thirteen per cent. Only in seven of the above sixteen reagents did this confusion occur.

The subject was then asked to pay particular attention to the visual appearance of the writing. With the right hand, this made very little difference; the reagent was apt to make one or two false starts, but in no case was a complete word reversed; and very soon he struck off in a rightward direction. With the left hand, however, the thirteen per cent of confusion was raised to ninety-one per cent. Only after the subject was familiar with the apparatus did he produce anything resembling letters; and then he usually guessed the purpose of the experiment, making further results of little or no value.

Using fourteen students who were unfamiliar with the apparatus, I attempted to find the percentage of meaningless figures that would be reversed. The tests I found most useful required the memorizing of a series of five figures by eye alone; the subject had then to put the prism before the eye and write off the figures with the right hand and then the left hand, without depending upon any particular control. Then I would caution the reagent to depend as fully as possible upon his visual remembrance of the figures; and again, upon the muscular remembrance. The next series involved the learning of a new set of figures, but principally by drawing them over and over with the right hand. Then after adjusting the mask, the

tests were repeated as in the series above. A third series was similar to the above, except that the left hand was the active member by which the learning was accomplished.

In the following table the method by which the figures were memorized is indicated as the "series". The "control" indicates the sense which the reagents were cautioned to depend upon. The first column of figures is the number of reagents, with, in the second column, the average number of their reversals in every twenty trials.

Some additional series were tried in which the learning of the figures was with the field reversed, and the test was with a normal field. Except that the reagents' surprise was a bit keener, the results were essentially similar to those of the series above.

PART III

THE EXPLANATION OF MIRROR-WRITING

1. The Physiological Factor in Mirror-Writing

The majority of authors agree that there is present in the right brain a centre which governs left-handed mirror-writing. Such an explanation very readily is suggested. The multiplicity of interpretations it permits allows infinite variation to accord with many diverse aspects of isolated cases. Yet I can not accept this theory as the most satisfactory explanation. I hold that a single "centre" is adequate to cause all of the manifestations of reversed writing. The very elasticity of the double-centre theory occasions complications, even contraditions, when one attempts to correlate all the cases and modified explanations and experimental findings. Again, it is against the concepts of modern physiology to think of a separate graphic centre—as such, or in any of the modified or reduced forms set forth by various investigators in this subject—as located in the right brain of right-handed indviduals. Also consideration of experimental data and study of the numerous cases reported in the

SERIES	CONTROL	RIGHT HAND		LEFT HAND	
		Reagents	Reversals	Reagents	Reversals
Series 1 (Mem. by eye)	General	11	0	10	0
		1	12	1	16
		2	4	3	12
	Visual	8	0	3	0
		1	20	4	20
		2	17	3	14
		2	12	3	12
		1	7	1	2
	Muscular	13	0	3	0
		1	4	2	8
				9	4
Series 2 (Mem. by right hand)	General	13	0	8	0
		1	6	3	12
				3	8
	Visual	12	0	3	0
		1	16	9	6
		1	7	2	4
	Muscular	13	0	4	0
		1	8	3	12
				6	8
				1	4
Series 3 (Mem. by left hand)	General	12	0	11	0
		2	4	2	8
				1	4
	Visual	4	0	2	0
		7	10	1	20
		2	8	9	8
		1	4	2	4
	Muscular	11	0	11	0
		1	16	1	8
		2	10	2	4

literature, has led me to believe that such a supposition is not necessary.* Therefore it is the purpose of this section to explain the basic motor complex which enables the unpracticed left hand to produce a skillful, automatic reversed script.

In this section, I shall treat only of this physiological aspect, and not of the psycho-physiological whole, which will be reached only at the end of the next section.

As an observed fact, there can be no question of the ability of the normal man to execute either consciously or unconsciously associated movements, that is, symmetrical accompanying movements. As I have already noted, the exact central complex involved in such movements yet remains a matter of conjecture. However, I should feel that this paper were incomplete did I not express an opinion as to the nature of what is evidently a firm organic basis for these movements.

This opinion is, that in every instance of stimulation of a nerve on one side of the body (primary stimulus) there is, by the arrangement of the central paths, opportunity afforded for stimulation of the corresponding nerve on the opposite side of the body (secondary stimulus). It will thus occur that the graphic representation of the secondary stimulus will be an exact mirror replica of the graphic appearance of the primary stimulus. Accordingly all symmetrical movements may be traced ultimately to a single brain area. From this area, the motor complex of the side primarily intended to be active receives its stimulus. The opposite side is stimulated to a lesser degree either by its direct connection with the primary area; or indirectly by its connection with the opposite motor complex; probably both means are available. For the purpose of mirror-writing it is most convenient to assume the truth of the second alternative—that the connection is between the motor cortices, through the corpus callosum. Evidence in favor of this contention may be summarized as follows:

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*Unless, of course, one be developed by *practice* of the left arm, which is evidently not the case in spontaneous left-handed mirror-writing, which occurs suddenly, and without forethought or practice.

(1) In the first place, the tendency of modern physiology is to attribute to at least those parts of the brain herein considered, the function of an "exchange board" rather than those of a "directing monarch".

(2) Muscular, or kinesthetic, or deep sensibility is mediated by the rich supply of afferent (sensory) nerves distributed to voluntary muscles, tendons, ligaments and joints. The impulses carried by these fibres to the brain are necessary for the proper contraction of a muscle, and especially for any co-ordinated movements. Indeed, section of the posterior spinal roots containing the nerves from any region is followed by a loss of control of the muscles of this region hardly less complete than section of the motor roots. The muscles are withdrawn from voluntary control in spite of the maintenance of their normal motor connections.[32]

(3) Within the central nervous system, the fibres of muscular sense in part pass by the median fillet (sensory decussation) to the cortex of the opposite side. They end in the postcentral gyrus. This cortical sensory area is connected by association fibres with the motor areas of the pre-Rolandic convolution. By this arrangement, a reflex arc is formed. The co-ordination of this arc with other areas is necessary for the act of writing, as it is for the completion of any voluntary movement.

(4) When voluntary movement is undertaken, there must be some definite condition to fulfill or satisfy by that movement. It makes no difference if the condition is the highly co-ordinated act of writing, or if it is some relatively simple act, such as a gesture. The ultimate mechanism is identical. One becomes aware that a certain movement should be made, which is sufficient to start the act. Then by differences in the deep sensibility of the various parts affected, and co-ordination of exchanges of these various stimuli in the brain, we get the movement completed.

(5) Let us suppose, somewhat schematically, that an impulse is sent from the so-called writing center (center for memory of motions entailed in formation of written language) which

should result in the formation of a letter. Possibly the movement could be started, but even at its birth the co-ordination would be snuffed out, and *random* movements at best could follow, unless the motor area is stimulated by the afferent muscular sensations. Sufficient proof of this phenomenon is afforded by breaking the circle on the sensory side.

Writing is the sum of a number of simple signs. For instance, when forming the letter *L* we have grown accustomed to certain kinesthetic sensations resulting from a downward and outward stroke. These sensations, or stimuli, are necessary for an *external* expression of the central memory. And an *L* is never made by an *inward* stroke—which gives radically different muscular sensations from an outward stroke. When the point is reached where the horizontal line should commence, its direction is either outward, or the movement stops, whether the left or right arm is being used. By virtue of this assumption, reversed writing will be the logical result of a left-handed attempt at written speech. For only this style will afford kinesthetic sensations which agree with the usual writing of the right hand. The most likely inference to be drawn from this observation is the participation of a single writing-centre common to ordinary right-handed writing and to left-handed mirror writing. The motor impulse originates in this single writing-centre, and is transferred either through the motor emissary of the left cortex to the motor emissary of the right cortex, or directly to the motor emissary of the right cortex. The former seems more probable in cases where there is no lesion of the left cortex, by analogy to more general cases of associated movements. The latter must be admitted as a possibility to account for the transferrence of impulses in those cases where there is a lesion of the left cortex (right hemiplegia); for the writing-centre, being but a specialized part of the general motor apparatus, may be supposed to be as intimately connected (by the corpus callosum) with the opposite motor cortex as is the general motor cortex.

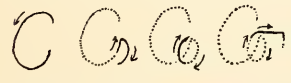
Or we may approach the question in another way. The fact

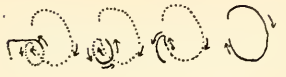
itself of the rich commissural connection of the two motor cortices would tend to detract from the hypothesis of the additional centre, by lessening the necessity for its formation. We will consider, first, that the greatest tendency for the hands to move sympathetically with rhythmic motions is in involuntary movements.*[39] [27] [66] Second, the tendency is only slightly lessened when one hand follows involuntarily the conscious (but random) movements of the other. Third, most conscious movements are not accompanied by a visible muscular contraction of the opposite part. Although the crossed innervations do not function, they are nevertheless potentially emitted by the ultimate motor source of the movement with only functional dimunition of power, as is demonstrable. Instance the ease with which associated movements may be consciously made. Fourth, we have no experimental ground for supposing these simpler transmitted movements to be interrupted at any place before reaching the motor area of the opposite side. Quite the opposite is indicated by the difficulty we encounter in attempting to make synchronous movements which do not correspond. Fifth, the simpler impulses being crossed by such a direct method, it becomes needless to assume the far more cumbersome complex of an added station so complicated in nature as a writing-centre.

A readier appreciation of the real simplicity of mirror-writ-

*In this connection, I cannot refrain from mentioning a few primitive examples of symmetrical accompanying movements. When the corpus collosum is directly stimulated from above, symmetrical movement on the two sides of the body may be obtained. Another interesting illustration is given by a case of Kraft-Ebing's [42 p. 29]. The patient is hypnotized and a figure, as K, is placed on one side of the body and suggested as hot; a blister is raised at this area, and also a symmetrical and reversed blister on the opposite side. Yet another example is found in the "scratch reflex", "cross-extensor reflex", etc., of Sherrington.[62] If one leg of a dog, for instance, be stimulated, the homonomous leg makes scratching movements, while the opposite leg presents slight steady extension, *with some abduction*. Now, the extension is a protective measure to support the animal on three legs while the fourth is scratching. We, therefore, have *abduction* common in both legs. I have found that certain variations of this experiment, such as placing the animal on its back or side, may result in faint scratching movements of the opposite leg. The fact that here we deal with an overflow spinal reflex in no whit detracts from the value of the analogy, for writing itself depends upon a reflex arc, which we may suppose to be connected with one higher centre, as here indicated.

ing will be felt only by grasping the similarity between unconscious corresponding movements, semi-voluntary corresponding movements, and highly complex corresponding movements, as shown by the above brief summary of observations on sympathetic motions. That is to say, any movement of one side of the body is accompanied by a potential symmetrical impulse to the corresponding part of the opposite side. This is a physiological or anatomical provision. The functioning strength of the impulse varies with the psychological state or condition of the individual. Thus a writer has only to learn the knack of disengaging and occluding the stronger functioning paths and letting the impulse function along the weaker paths, to have the usually non-functioning impulse result in a skilled movement of the so-called unpracticed side. In other words, the table is turned, and the one system now occupies exactly the same position formerly held by the other. With this manipulation fully accomplished, the *visible* accompanying movements of the right hand become unnecessary for a fluent mirror-writing by the left hand. With a lesser degree of dissociation we have the characteristic mirror-writing that occurs in simultaneous writing with both hands, the attention being directed to the right hand while the left hand trails along semi-automatically. Or, simpler still, writing simultaneously on both sides of a sheet held in front of the body and in the sagittal plane.

There are additional objective phenomena confirmatory of the absence of the secondary centre. Those that are based on synchronous writing are so easily verified that I need scarcely more than mention them to have their bearing appreciated. It is easy for the average reagent to reverse his right-handed writing if his attention be given to his left hand while this left hand is forming normal writing. All the peculiarities and superfluous stroke, characteristically made by the left hand (e. g.  for the usual right-handed formation ) will be faithfully copied in reverse by the right hand (i. e.



Again, it is practically impossible for any reagent that I have dealt with to write different letters *synchronously*. I have myself attempted this repeatedly but have acquired little skill in the performance.

I repeat that I am unable absolutely to refute the possibility of the additional centre in the writing complex. I have therefore collected a mass of evidence both for and against, and have formed from this my judgment. Thus, it might be that every movement of one side of the body is accompanied not only by a potential, but by a feeble symmetrical impulse to the corresponding part of the opposite side. By constant repetition, as in writing, the paths conveying these impulses would become more easily traversible—paths, in fact, that would be defined in exact proportion to the practice of the functioning side.* In this way a centre might become sufficiently formed to control left-hand mirror-writing in case of lesion of the left brain. Yet it would seem that even if such a supposition were tenable the centre need not be located in the right brain, since symptoms of apraxia on the left side in injuries to the corpus collosum have been reported, in which there was no lesion of the right cortex ([32] p. 229). Again, it is usually the uneducated right hemiplegic who resorts to mirror-writing. Did an additional centre control left-handed mirror-writing, one would expect exactly the opposite, for the centre must be developed in exact proportion to the practice of the right hand at ordinary writing.

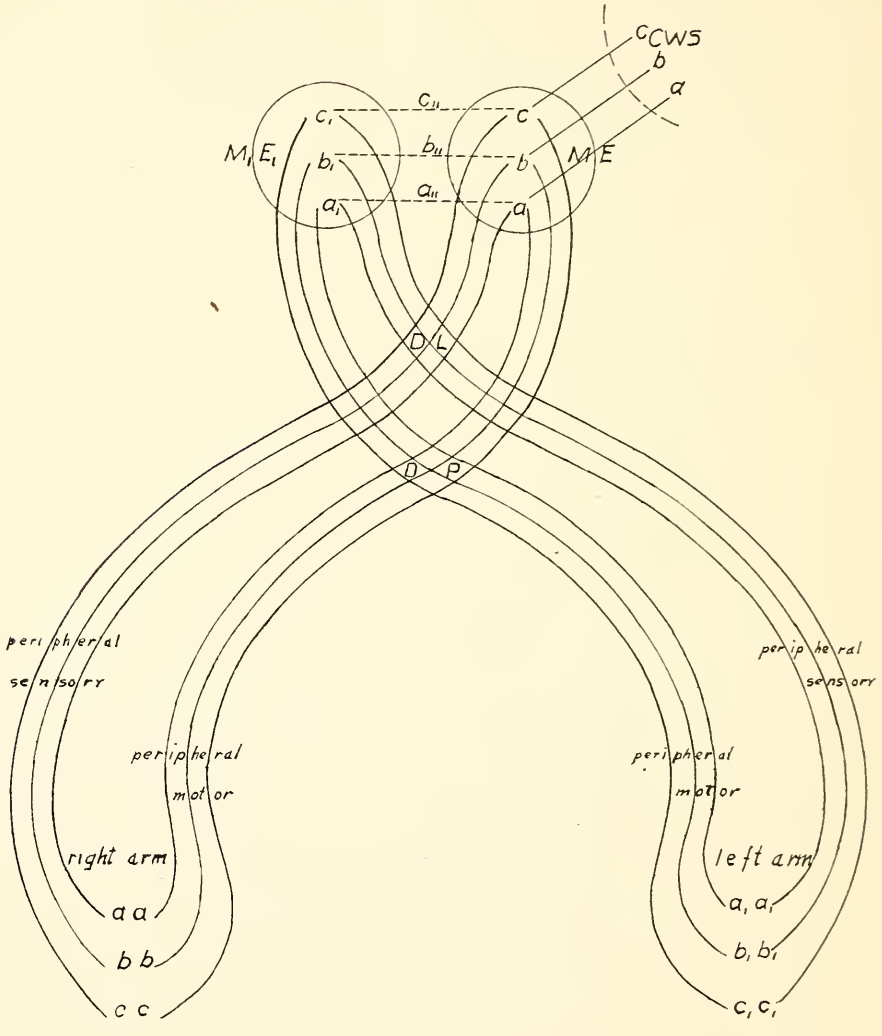
It seems to me that the best argument for the bi-lateral representation of the writing centre is that the faculty of mirror-writing has in rare cases been suddenly assumed by the left hand after paralysis of the right hand due to central lesion. The assumption in many instances has been that the central lesion has involved and destroyed the writing-centre of the left hemisphere. However, there is some doubt cast upon the location of the writing centre in Broca's convolution, as has been shown by some recent work by Marie. I know of no cases of

*See footnote on page 246.

mirror-writers, where to conclude from post-mortem findings, or from the study of aphasics or hemiplegics, that the writing centre, *as such* has been destroyed would not become extremely hazardous.

The writing-centre is a motor memory centre, developed by practice, and causing the formation of writing to be an automatic rather than an attentively controlled process. Yet it is never so automatic as even such complex acts as reading and speaking. It is superior to the motor area of the brain, in that the motor cortex is merely the emissary area, or the connection between higher centres and motor nerves. The writing-centre was originally identical with these higher, intellectual areas, but has become in a sense detached from them, and reduced to a unity by the forces operating to make it a physiologic sending station, requiring the least possible participation of the higher centres. Were the writing-centre alone destroyed, the patient might again learn to write as he did in the beginning. Clearly, the left-hand writing of such an individual would not be mirror-wise in any greater proportion of cases than the left-handed writing of the perfectly normal right-handed individual or of the right-handed child, who when asked to write with the left hand scarcely ever reverses. The only difference between this case and a right hemiplegia supposed to involve the writing centre, is paralysis of the arm. And in fact but a very small proportion of right hemiplegias are accompanied by mirror-writing. These cases in particular have been cited as evidence of destruction of the left-brained writing-centre. But then, may one not ask why the normal individual when using the left arm is not just as dependent upon the centre of the right brain as if the centre of the left brain was destroyed? In other words, use of the left arm should imply dependence upon the opposite centre, which means mirror-writing, whether or no the centre for the right hand is destroyed. Should the use of the right leg be preserved in a hemiplegic mirror-writer and the patient be unable to write rightwards fluently and automatically with this limb, it would be strong presumptive evidence that only one of

two writing-centres was destroyed, but I have never heard of such a case.



C. W. S. Centre for motor memory of written speech, which is identically related to kinesthetic sensations from either side of the body, those from the left arising from the movements of mirror writing.

M. E. Motor emissary of left cortex.

M_i. E_i. Motor emissary of right cortex.

D. L. Decussation of lemniscus.

D. P. Decussation pyramid.

a, *b*, *c*. Graphic demonstration of musculo-sensory innervations of right arm, which are correspondingly related to a_i. b_i. c_i. of the left arm, and to the commissural impulses a_{ii}. b_{ii}. c_{ii}.

All this leads to the conclusion that mere paralysis of the right arm has very little to do with mirror-writing. The presumption that mirror-writing depends upon the retention of the single writing-centre is therefore more logical than the assumption of an additional centre to account for reversed writing.

In the schema on p. 236 the idea embodied in the above discussion is summarized.

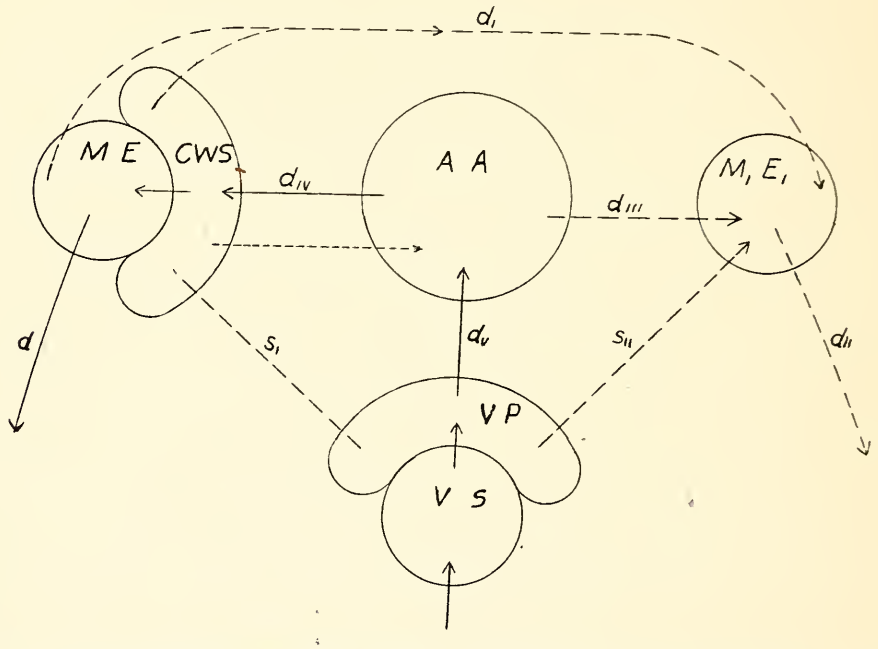
For the motor fulfillment of the act of writing we may suppose two essential steps: the first and lowest is the simple reflex arc, involving the motor areas; the second forms the connection between the writing-centre and the reflex arc. In associated movements in general, the primary impulse is received by but one motor cortex. From here a secondary impulse is transferred to the motor cortex of the opposite side. Mirror-writing, being but a specialized instance of associated movements, may be expected to follow this course. Destruction of the writing-centre will cause a loss of the faculty of habitual, or automatic writing, both by the right and left (mirroring) hand; but does not prevent the regaining of the ability to write by again repracticing the art with either hand.

2. The Psychological Factor in Mirror-Writing

The fundamental physiological relations which make of associated movements the simplest response to a bi-lateral stimulus, points to the validity of the conclusion of Buchwald;[13] Vogt;[68] Durand;[21] Nicolle and Halipré;[52] Ballet;[6] Meige;[49] Figuera;[25] Laprade[44] and many others cited herein, that the reversed style is the normal writing of the left hand. May one not ask, then, why mirror-writing is not the universal style followed by the left hand? Why is left-handed reversed writing not the rule rather than the exception? Were it not for some inhibiting influence, one would expect this to be true in the majority of cases. By a study of the cases adduced in the literature, I was led to the belief that this inhibition could be removed by

experimental methods. The nature of this psychological factor, and its relation to the experiments just reported, is set forth in this and the following section.

If you will recall the example of the letter *L* (given on p. 231), it was stated that the horizontal line will either be



s_i Connection between visual area and motor emissary of left brain.

s_{ii} Connection between visual area and motor emissary of right brain.

d Emissary fibres from left brain to right arm.

d_i Commisural connection between writing centre and motor emissary of right brain.

d_{ii} Emissary fibres from right brain to left arm.

d_{iii} Connection between the association area and the motor emissary of right brain.

d_{iv} Connection between association area and writing centre.

d_v Connection between visuo-psychic and association area.

V. S. Visuo-sensory.

V. P. Visuo-psychic.

A. A. Association area.

M. E. Motor emissary of left brain.

C. W. S. Center for written speech.

M_i. E_i. Motor emissary of right brain.

Modified from Lickley.

continued outward, or will not be drawn. The latter alternative will exist only if the former process is interfered with by our higher conception of what an *L* should be, i. e., how it should appear when on paper. With the visual significance of the anticipated movement as guide, the line will certainly be directed inward, supposing that the left arm is being used. By the inclusion of this element, embracing the 'visuo-psychic,' 'visuo-sensory', and 'association' areas, the provisional diagram on page 236 may be completed as in the figure on page 238, opposite.

To write from left to right with the left hand implies that the activities of the paths s_{ii}, d_{iv}, d_v, d_{iii}, (s_i, d_i are involved in the process, but to a much less degree) must be abnormally increased to the complete minimizing of the grapho-motor control as described above.*

Since the grapho-motor control is the simpler and physiological control, and is provided for by the arrangement of the central motor complex, I maintain that rightward writing by the arm on the same side of the body as the writing centre, is, usually† of the character of *drawing,* as contrasted with that of writing. For by "writing" I understand the smooth, easily flowing, spontaneous, nearly automatic series of movements which through training follow each other without the necessity of direct participation of the conscious or intellectual centres at whose instigation the process originally arose. Entirely the opposite of this facile, I might almost say unconscious, sequence is the labored, sometimes painfully conscious, visually supervised and poorly executed left-handed rightward "drawing".

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*See Part III, Section 1, pp. 227 ff.

†"Usually" refers to the *occasional* use of the left arm (or the right arm in the left-handed individual), to distinguish this condition from the persistent left-handed rightward writing following permanent injury to the right arm, or the sensori-motor arc, and in which there are two possibilities for the writing to become automatic: first, the gradual formation of a new centre under the influence of constant practice controlled by the visual areas; or, second, the persistence of the more complex "drawing paths", including the participation of the old writing-centre, which by practice becomes semi-automatic. The end results are identical.

The impulse from the grapho-motor apparatus which, if unrestricted, would cause a left-handed mirror-writing, suffers by its reversal; by the addition to it of various impulses from the visual and association areas; and by the interference with the free passage of the impulses occasioned by the participation of the same higher centers which made possible the birth of the writing centre. Conversely, left-handed reverse "writing" would occur in direct proportion to the degree of suppression or inhibition of the interfering paths, from the visual and association areas, or—what amounts to the same thing—with the increasing canalization of path d_i.

We must remember that the visual complex predominates as an absolute "control" only in left-handed left-to-right writing. Using the right hand, we may attempt all sorts of confusions on the visual sensations, but they will never usurp control from the automatic habitual control of writing. This circumstance is well known by the following experiment: Place the right arm on the desk in a position for writing; then curve it inward, at the same time throwing the shoulder forward until the hand points toward the mid-sternal line of the body; a completely inverted writing will now be found far more natural than writing which to the eye appears normal. Only the *legibility* of our ordinary writing depends to a very great extent upon the visual stimulus. Thus, for proper spacing, for alignment, for the equality of letters, to avoid losing the way when in the midst of a word and so misspelling it; in general, for purposes of orientation, sight is quite necessary.[65] But this direct visual guidance may be dispensed with, although the central memory and the sensori-motor arc are indispensible. An observation of no little significance is that we regard the letters just written, and do not follow the movements of the fingers or of the pen point in tracing individual signs. Here is the most obvious distinction between the external visual control, and the "internal writing", as it has been termed. The former immediately follows, the latter immediately precedes, the writing of the letter ([65] p. 61).

There is, as I have indicated, one type of mirror-writing which is purely automatic. For obvious reasons, it is this type of mirror-writing which most interests us. But there are two other controls which may influence one to a reversed writing. One is the voluntary visuo-muscular transposition of the motions made in forming the letters in reversed form. The other is the confusion of the lateral relationships of objects in space. These three control factors may be combined in any proportion; but each, if present as the major influence, will result in the production of a type of mirrored lettering that is distinctive.

The second type of control, then, occurs when one voluntarily endeavors to reverse his writing. If the condition extended no further than the conscious and attentive endeavor, it would have little to do with my problem, which is concerned primarily with the automatic reversals of the left hand. For until one gains some confidence in the use of the left hand; that is, until he has practiced writing somewhat with the left hand, this attentive form of reversal may be executed almost as well with the right hand itself. However, one should remember that here, as in every instance where a right-handed individual writes mirrorwise with the left hand (or *vice versa)* the mechanical or commissural fibres have been "trained" by the practice of the right hand. As one practices left-handed intentional mirror-writing, he feels the influence of this factor in a constantly increasing degree. He soon realizes that left-handed mirror-writing is far easier than right-handed mirror-writing. And before long he regards left-handed mirror-writing as easier than left-handed rightward writing; that is, the mirror style requires less attention, and is therefore more freely and rapidly written. However, without this preliminary practice one finds it practically impossible to dissociate what I have termed the psychological factor, or briefly, the attention, without the use of such artificial methods as are described (on p. 215 ff.) with the experimental relations. But when such devices are used, the mirror-writing is probably no longer attentively controlled, but is of the nature of an automatic reversal. For the same reason,

attentive or intentional left-handed reversals which have been practiced are to be regarded as having passed more to the automatic class of control.

This may be of interest, in that a possibility is suggested for the mode of origin of some cases of pseudo-spontaneous mirror-writing. It does not seem improbable that some people, through some whim would practice reversed writing. Finding this the most satisfactory style, both in ease and quickness, they might persist in its use till the conscious transposition of the images became unnecessary; that is, until the process has been relegated from the more essentially attentive to the more essentially automatic systems; until, in a word, we have an automatic reversal acquired through practice, which step is usually omitted.

The third type of control for reversed writing is contrasted in every way to the second type; it is due to confusion of the lateral relationships, and is for this reason always of a fragmentary character where unassociated with the other controls. Hale and Kuh[31] have called attention to the fact that this type of reversal is almost universal with the right hand of normal children of a certain age. Considering only the element of confusion, one would expect that the proportion of reversals by the left hand would be slightly higher with the same children, due to a greater disorder experienced in writing with the left hand the same confusing lines that are so often misdirected under the more favorable conditions of right-handed writing. We must not fail to consider, however, that as left-handed reversals are always aided by the physiologically crossed motor-complex, the left hand is more prone to this, as to other types of reversal. If this process of confusion be exaggerated sufficiently, the influence of the crossed automatic paths in contrast to the influence of the paths of attentive control will be so great that the fragmentary left-handed reversals will become complete, and a true automatic mirror-writing will result.

The left-right relations of objects in space are extremely elusive. They are acquired last and with most difficulty, are

hence easily confused in the process of learning and are the first to be lost in a process of spatial degeneration. Instances to the point are legion, and one has but to try an habitual movement before the mirror, or to watch a squad of recruits in facing movements to be convinced. On the other hand, above-below relations, being more fundamental, are rarely confused, which would explain the fact that spatial confusions of writing are so seldom those of fragmentary inversions. We may well expect, then, the normal right-handed writing of children at a certain stage of their development to be fragmentarily reversed, especially such confusing letters as *S* and *N*. Exactly the same incomplete mastery would explain the fragmentary reversals of uncultured adults. Add to these facts the condition that through some (usually central) lesion the left arm must be used by an individual who is strongly of motor tendency, and we need not be surprised if he is inclined to ignore the confusing, purely sensory relationships, and completely reverse his script; i. e., to rely upon the habitual, or motor, complex, rather than upon the intellectual complex of writing.

Conversely, we should expect the educated person, with his thoroughly mastered relations, not to be baffled by any condition comparable to that above. But what might ensue if this individual (or, as well, the uncultivated person) should combine aphasia with the enforced use of the left hand? All forms of aphasia, according to Marie, are due to interference with the posterior association area. But the only injury that can cause pure motor aphasia is injury to the lenticular nucleus. Motor aphasias are therefore due to a combination of cortical injury in the posterior association area (aphasia proper) and a subcortical injury (anarthria). As a corollary to this, aphasia is always associated with an impairment of the intellectual powers. Now, would it be assuming too much if the mirror-writing which follows hemiplegia were attributed to a similar circumstance? We should remember that mirror-writing but rarely follows cases of hemiplegia involving the left hemisphere. It may well be that the lesion in these exceptional instances is essentially

similar to a circumscribed aphasia. Or, at least, the lesion might cause disturbances comparable to a functional dissociation of the attentive from the automatic controls. Unfortunately, I have had an opportunity of studying only two cases of hemiplegics who could write at all. Both of these patients were confined in an institution for the insane. It would be unsafe to draw any conclusions from the fact that one would write, with the left hand, only in the reversed style, though the analogy is startling. My reasoning is therefore entirely *a priori*.

The "normal" or "abnormal" significance of mirror-writing forms a question of no slight importance. In attempting to decide it, I have been confronted with the ambiguity of the terms, which are apt to lead to some confusion. In ordinary writing, ideas are converted into the form of words which are transferred to the motor system and expressed as written speech. But writing with the hand not accustomed to writing is a novelty, and as such brings into play additional elements such as increased attention, which are ordinarily sufficient to influence the writing, in order that it may be legible to the writer. If these factors are prevented from increasing, or are reduced below the level they occupy during ordinary writing, the crossed motor complex may express itself in the form of mirror-writing by the hand accustomed to writing. However, one can not suppose that a novel event such as left-handed writing could occur normally uncombined with increased attention, unless the other extreme —dissociation—is reached. The fact that one appreciates this use of the left arm as something new or unusual focuses his attention at once upon the act. If not, something abnormal is indicated. And the attention, we found, is of first importance in reducing the probability of a reversed script. If, however, because of the presence of the crossed motor complex, we agree that mirror writing is "normal" to the left hand, we must consider the inhibition of this property by the attention as "abnormal". Hence the answer to the query depends upon which of the processes we choose to call the "normal" control.

My experience has led me to consider both the reversed

and the ordinary script, or neither of them, to be "normal" and for the following reasons:

(1) Mirror-writing is for the left hand the simplest, most direct, and essentially the automatic motor expression, involving *only* the primary central motor apparatus. It is, therefore, the "normal" motor automatic script.

(2) But the fact of its "abnormal" appearance, both to the eyes, after it is written, and to the perception of the writer during the act, makes it a distinctly "abnormal" entity.

(3) Left-handed rightward script will, according to the above, be "normal" for the higher centers, and "abnormal" for the habitual crossed motor apparatus.

(4) The knack of mirror-writing can be acquired with facility by anyone. Yet of this latent power the vast majority of mankind is unaware. But one may not argue that the ease of its acquirement constitutes normality for a process. Nor can we suppose that the rareness of a thing makes it abnormal. We may say, however, that during the periods of acquirement, we deal with an "abnormal" process, which becomes "normal" when the higher attentive control is dissociated with ease and habitually.

(5) There can be no doubt of the normality of a certain percentage of fragmentary reversals by the left or right hand by children and by unlettered adults. The confusion of the lateral relationships occurs quite naturally in the course of development. They are more "normal" than are experimentally induced reversals, or than "normally" occurring complete reversals, because the dissociation is but mementary, is less complete, and the writer is unconscious of the reversal, at least until after it has been recorded.

I would say that the fundamental perviousness of the automatic as against the attentive paths is so much a matter of individual idiosyncracy that no line may be drawn between the physiological and the pathological. The one extreme—namely, fragmentary reversals and practiced, intentional, mirror-writing —is clearly perfectly normal. The other extreme—sudden,

spontaneous, complete reversals—certainly results only from organic or functional lesions having the nature of a dissociation. While the apparatus favoring reversals is always present as a physiologically normal entity, yet the functioning of the crossed impulses indicates, in extreme cases, great nervous disorganization.

3. Experimental Relations

The simplest experimental verification for my argument is the ease with which subjects in the hypnotic trance may be induced to write mirror-wise. Charlatans have frequently taken advantage of so evident a means to impress their audience with the supernatural import of some message. Mediums and others have, doubtless in all good faith, placed this supernatural interpretation on their accidental left-handed mirror-writing, which is apt to occur in auto-hypnotic trance states. Special directions are not generally necessary, aside from insisting upon a left-handed response. Appropriate suggestions may at times be of aid; for instance, the subject should not be aware that he is writing in any but the normal form. And why is hypnosis a favorable—nay, the ideal—condition for reversed writing? The answer is at once that the response of the automatic mechanism is more completely relieved of the attentive control than in any other condition. The diffused activity of the brain is limited. The impulses, being confined to a restricted area, tend to follow faint "traces" (i. e., crossed impulses are more free to function) from which they would otherwise become deflected (by the attention) were the content of consciousness larger. All "paths", except d_i of the schema on p. 238 are occluded by the conditions of the experiment. For the same reason the "channel" d_i is "deepened and widened".* The writing will be reversed because of the identical muscular relation between it and normal writing by the right hand. Ordinarily, this relation is disturbed by the interference occasioned from the visual centre. Ordi-

*The assumption of these brain-conditions is supported by Robertson.[58]

narily therefore, the path d_i does not function as one simple link between the writing centre and the muscles of the *left* arm, similar to the corresponding link for the right arm.

No less striking is the effect of certain drugs[19] in facilitating the production of mirror-writing. There may be some little difficulty in handling a person sufficiently influenced by the substances for our purposes, but if he be prevailed upon to write at all with his left hand we may confidently expect at least fragmentary reversions. Thus, one who was in just the proper state of advanced alcoholic intoxication refused to move his left arm in any but the reversed direction.* Other subjects, more moderate in their potations, exhibited lesser inclinations to reversals. In fact, the greater number of any tests indicated a direct relation between the degree of intoxication and the extent of the left-handed reversed responses. The more advanced intoxication favors complete reversals, while in the less complete stages of intoxication there occur few or no reversals, even of a fragmentary character. The most satisfactory stage, all considered, is one in which the shifting of the two conditions obtains. One may see beautiful illustrations of the nice balance between the two control factors that this state favors; at one moment the muscular responses are mainly governed by the grapho-motor stimuli; the next moment, the patient realizes that there is something amiss and attempts to correct the error. There is an instant of confusion accompanied by random, indefinite, motions of the arm. Then the subject gathers his scattered wits, concentrates his attention upon the task of making unintelligible signs, and for a longer or a shorter time actually adheres to this design.

Ether and chloroform† present essentially the same phenomena. In all of the drug tests I was most careful to avoid any suggestions which might lead the subject to suspect the purpose of the experiment, as the mental condition under

*See p. 217.
†See p. 219.

these drugs is one which lends itself readily to suggestion. These drugs are all narcotics. As such, they inhibit the passage of impulses through the central system, the formation of associations and of traces. "Obviously", says Robertson[58], "such drugs must tend to limit the field of consciousness to the regions most vividly stimulated . . ." What could be more favorable for our purpose? By inhibiting the passage of impulses, it would result that the commissural traces, being already formed, in however slight degree, would be more easily traversed than the potential link with the visual area. The formation of new associations is more essential to unpracticed left-handed rightward writing than to mirror-writing. This is so apparent as not to need comment, I think. With the initial attempt at left-handed centripetal writing, new "traces" must be formed, whereas we may see that "traces" conducive to left-handed mirror-writing exist with the practice of the right hand. Lastly, we have the field of consciousness limited to the left arm and the writing mechanism, i. e. the endeavor is notably motor, as the higher, the attentive, fields are the first to be depressed by the drugs.

The action of Cannabis Indica* is peculiar to our problem. It has long been regarded as especially facilitating the passage of impulses through the central nervous system. If one were a practiced mirror-writer, and it were *suggested* to him that he should use only this style with the left hand, then mirror-writing under the influence of this drug should be extremely easy. This, in truth, was exactly what occurred when I ate the hemp. But an entirely different set of influences intervenes if the impulses are not directed into the mirror-writing "paths" by some such forces as those operating in my case. The activities of the higher, attentive, or intellectual parts of the brain are increased. We should expect, then, to have the "drawing" paths for the left-handed centripetal writing more intimately connected with the motor area of the right cortex, in view of the fact that *all* paths are more easily traversed. However, in

*See p. 218.

the two cases I have been able to test, I gained, in one, almost a pure mirror-style with the left hand. The other showed considerable confusion, but wrote mirrorwise in but a small percentage of trials. No doubt the explanation lies in the peculiar dissociative action of Cannabis Indica. In the classical description of the action of the drug[70] the individual's attention is so occupied in observing the flights of his imagination, possibly revelling in the visions, or in analyzing his state of consciousness, that the motor part is left largely unhindered by the usual attentive supervision. My hypothesis is that under precisely these conditions there will be a relatively stronger predilection towards mirror-writing than towards rightward left-handed writing.

An abrupt transition to the survey of the less evident causes of dissociation is instructive. Perhaps the most impressive example of this sort is the sudden reversion of adults which may follow functional loss of the right arm. Hemiplegias have been fruitful in calling the attention of observers to mirror-writing. Instances of injury to the right arm have been noticed to precede reversals. Merely intense occupation of the right arm favors synchronous mirror-writing with the left arm. Witness the case of the telegrapher who often jotted down messages with his left hand, while tensely operating his key with his right, and who was frequently surprised at finding the written words reversed.[50] I have personally questioned forty telegraph operators, and found that not uncommonly, under similar conditions, many of them have noticed confusion in their writing, though not all of them were sufficiently interested in these confusions to remember them definitely as reversals. Now I have found, both in the published cases and by personal experience, that there is a direct ratio between the intellectual control and the amount of dissociation necessary to bring about mirror-writing. If one glances over the conditions which favor the spontaneous occurrence of mirror-writing* he will observe that there is supposed either a low grade of intelligence or a disturb-

*See pp. 201-202.

ance of the higher faculties. And this we might expect, for there is less to dissociate in the unintelligent. That is to say, we have two grades of intelligence to both of which writing is common, and both of which possess, therefore, the ability to write mirrorwise with the left hand. The circumstance that the left arm gains in skill in direct ratio to the practice of the opposite arm, i. e., to the development of the writing centre in the left cortex, will, of course, be more favorable to a better mirror-writing by the higher intelligence. But this is rendered relatively unimportant by the greater corresponding increase of the psychological content and training, which is directly antagonistic to mirror-writing. There will be, therefore, a greater number of conditions favoring an unintelligent mirror-writing. Conversely, it will be most difficult to induce the highly educated writer to reverse, but once this is accomplished, the reversals will be much more legible, complete, uniform and automatic. This is apt to be true because to get automatic left-handed writing at all we must attain more nearly that ideal property of dissociation and suggestion which is most favorable to mirror-writing. Whereas, in the unintelligent a much lower degree of dissociation and suggestion, both relatively and absolutely, will suffice. For we find that the higher we go in the scale of intelligence, the more is the purely motor expression of brain activity subordinated to some form of expression more compatible with cultivation. Mirror-writing is not ordinarily a thing which seems to intelligence to be expressive of beauty or usefulness, and is, therefore, unless by some whim or perversion, not tolerated.

But if the higher intellectual content can inhibit mirror-writing, then a reversed vision should aid in the production of reversals, for vision is a most important guide to motor expression of the psychic areas. However, the data I obtained was absolutely contrary to my expectations.* With the inhibiting visual field converted into a support of the commissural paths, the subject ought soon to orient himself, and plunge boldly and

*See pp. 226-228.

naturally into centrifugal writing with the left hand. But the reagents calmly ignored the visual element, and wrote centripetally with the left hand; and when they attended particularly to visual control, only confusion resulted, with nothing so much as indicating any actual progress at writing. In seeking for an explanation of these phenomena, which at the time of their trial apparently so completely refuted my hypothesis, I had the reagents memorize sets of simple figures and then reproduce them with the field reversed. A marked individuality was shown in the tendency to reverse the figures. The majority of subjects, however, if left to their own devices, reversed but few or none of the figures, even with oft-repeated trials. With the right hand, reversals were extremely rare; and when they occurred, they showed a tendency to persist after the prism was removed. That is, they seemed to be errors of memory rather than confusion occasioned by the reversed visual field. Errors were more frequent when the left hand was used, and did not show a corresponding tendency to persist after the removal of the prism from before the eyes.

We may infer that the "muscular" remembrance of the right hand, of right-handed individuals, is much more certain or reliable than the left. Also that the external visual element may interfere with, confuse or control the movements of the left hand to a greater extent than the right. But the latter factor is, after all, only of slight import to the motor memory complex, even in such meaningless figures as those used. The confusing prism aroused the subject's attention, warned him to avoid the unsafe visual influence and to place his faith in the more reliable memory impressions. Muscular action is in imitation of the direction of the thought. Herein, I think, lies the reason for the control assumed by the majority of subjects in voluntarily reversing their left-handed writing. After the various tests, I had every suitable subject practice this style of script. The majority sooner or later agreed that it was necessary only to keep constantly in mind the necessity for reversing the letters, or to think of the general writing direction, or to start a

letter in a reversed manner, to have the hand complete the letter with little or no attentive guidance. The attentive and the grapho-motor elements were working hand in hand. It is but another step to suppose that without sufficient attention, or with the proper kind of confusion of the attention, the grapho-motor complex may take charge and produce a left-handed reversed script.

In the writing of adults with the left hand, I see a process comparable in some respects to a certain stage in the history of the individual acquisition of written speech. Where a child, for instance, has just thoroughly learned the appearance of his letters, he devotes extraordinary attention to making his copy as nearly like the original as possible. The two processes—the visual appearance of the letter, and the tracing of a likeness of the same visual form—are so closely linked together as to be practically a unity. I carefully studied eighteen such children and observed some forty others of approximately the same grade of experience, and none of them evinced the slightest inclination to left-handed reversals. Nor could they be induced to reverse; confusion and return to the usual appearance of the letters supervened in every instance that reversing was tried. In a like manner the adult of average intelligence thinks it impossible to reverse his writing. And if he does succeed, he usually calls upon his greater experience to reverse the mental image of the visual and motor "appearance" of the writing.

At a later period, the child shows a considerable tendency to become careless. Perhaps his joy at having finally mastered the intricacies of graphic language incites him to over-confidence in his ability to write invariably a correct copy. Probably, too, the preponderating visual control has been somewhat replaced by the automatic system of writing, which is closely linked on the motor side and but feebly bonded on the visual side.* It is then quite easy to throw the child off his guard, and secure whole words in mirror form. I found in a preliminary study of eight children of this age that some simple sub-

*See pp. 238-241.

terfuge such as having the child write rapidly two closely connected words, for instance, "Berkeley, California", or the date, (but, between the words, having the paper turned rapidly about through an angle of 180° in its own plane), was often sufficient to cause the second word to be reversed.* A specialized confusion is aroused, with as little introduction of absolute suggestion as may be.

It will perhaps be advisable to consider a few of the published cases of mirror-writers which may not seem compatible with my argument. Type case: E. M., a paralytic imbecile girl of seven years, hemiplegic since birth; when learning to write with the left hand, she persistently produced mirror-writing.[38] Compare such cases of left-handed children learning to write with the interesting report of Kingman.[42] A teacher injured her right hand. She easily wrote mirror-wise with her left hand and found it more convenient to give copy to her pupils in this style till she recovered. The children used a mirror to read their copy. Three of these children were examined by Kingman and found capable of mirror-writing with either hand, easily and rapidly. There is a ready explanation for these occurrences of mirror-writers quite aside from the interpretations that might be drawn from the consideration of a possibly altered central motor complex. The tendency for children to mimic the motions of others is proverbial. I have had occasion to observe this inclination in a large number of cases. The average child will blindly follow any movement of one in authority, thinking, no doubt, that it is all a matter of the queer, grown-up idea of propriety, to be adopted without question by the child. This is especially true of deaf children, who rely more upon vision and who are more apt to subordinate other faculties in their endeavor to follow the meaning of their instructor. Even more would this be true in the imbecile attempting to imitate obvious graphic signs ([65], p. 83). There have been cases reported where defective sight was associated with the mirror-writing of children. In one instance, upon

*See p. 223.

removal of this reflex irritation, the writing at once became rightward, and if the corrective glasses were removed the writing was again mirrorwise.[64]

Now, the centrifugal direction, being the biggest and most easily grasped feature of writing, is apt to be seized upon first by the child, especially if sentences rather than letters are used. The child is imitating with his left hand a series of motions made by the right hand of the instructor. Then, too, the symbols which the instructor forms have very little meaning to the child who is just learning to write, hence his reversal of them will have little or none of the unusual in their appearance. If the child is allowed to continue to practice the reversed form, it will become habitual, which will mean merely that he has learned his letters in reversed form. Ordinarily this process is not allowed to continue to such an extreme. Occasionally however, this does occur, as is shown by several cases where reversed writing could be quite fluently read.* As such cases are able to read ordinary writing, it would seem that they have simply acquired an additional alphabet-complex in their reading-centre, by which they are enabled to interpret mirror-writing. It is not necessary to assume a visual disarrangement of any sort to enable one to read mirror-writing, since all who are able to do so either are mirror-writers, or have had experience with mirror-writing. Without this experience, which must be quite extensive, the person will find it necessary to run his eye backward over a word, thus deciphering every movement as it was made when forming each letter.

The different central relations that might be noticed in the various writing combinations of the left-handed, and various ambidextrous tests, form a tempting subject. But this is a question which I have been careful to avoid as beyond the scope of my problem. At best, a consideration of these relations could but lead us further into the field of the hypothetical. However, I may mention the following as a possible explanation

*Most congenital mirror-writers can read reversed writing fluently.[12] Most cases are unable to realize the copy as different from the text.[64]

of why there is a greater tendency for the left-handed child to write mirrorwise with the left hand, than there is for the right-handed child to write mirrorwise with the left hand. In the left-handed, the seat for the development of a centre for written speech is presumably in the right cortex. But the child is not allowed to use his left hand for purposes of writing. We should remember that upon the use of the right hand for ordinary writing depends our ability to write mirrorwise with the left hand. Now the language-complex in the present case is such that we may suppose the writing impulses are carried from the right cortex to the emissary area of the left cortex and thence to the right arm. An extra step is added. Hence, if the child does occasionally use the left hand, this extra step will be dropped. His left-handed writing is therefore simpler than the left-handed writing of a right-handed individual. Accordingly there is a greater tendency for the impulses to function unaltered in the left-handed child. What seems to me to be a confirmation of this opinion is given by Hughes[33] in a report upon his own experience. He was congenitally left-handed but was taught to write with his right hand. He was troubled for a number of years by the difficulty he experienced in so writing. Finally he hit upon the device of writing everything with his left hand mirrorwise, on thin transparent paper, and turning these sheets over when he wished to read them. Left-handed mirror-writing obviated all the tediousness of rightward right-handed script. I postulate that a writing-centre was developed by the right-handed practice; that left-handed rightward writing would necessitate reforming this complex into entirely different relations; and that the primary facility of left-handed use tipped the scales in favor of an automatic, rather than of an attentive control. Any double-centre hypothesis (which Hughes himself favors) would be inadequate, because if there was a separate centre in the left cortex, it would be this centre which would be more highly developed by practice of the right hand; the "overflow" into the right cortex would be relatively less, and the difficulty of writing automatically with the left

hand would be greater instead of less than that of the right hand, in spite of the fact of left-handedness.

While there is probably some such contributing factor as that outlined above, the safest and best explanation lies in the simple fact that the left arm of the left-handed child is the one preferred for all of the delicate operations ordinarily performed by the right hand. Use of the left hand for writing will therefore be a more thoughtless, a more automatic, reaction than a similar action by one who is right-handed. And an automatic writing presupposes a proportionate increase in the control of the motor complex of writing; which in turn, is more favorable to reversed writing. It is a necessary condition that the child must have had some practice with his right hand at ordinary writing. Otherwise, there will be no reversals by the left hand, for those who have been allowed to use their left hand freely and from the first, find rightward writing as easy as do the right-handed.

There is an interesting question opened here, which I unfortunately have thus far been unable to investigate satisfactorily. That is, will left-handed writers, when placed under the same conditions which favor a left-handed mirror-writing by the right-handed, produce mirror-writing with the right hand? According to my argument they certainly should. Obviously the experimental difficulties would be far greater. Thus, it is a difficult matter to find left-handed writers who have not at some time been forced to practice right-handed writing. Such practice would, of course, introduce a new element into the writing complex, and make these subjects unamenable to corresponding tests given the purely right-handed or left-handed writer. Of numerous left-handed persons investigated, but one could claim entire freedom from attempts to enforce the use of the right hand. The right-handed writing of this reagent was subject to experimentally induced reversals in a manner analogous in every respect to the left-handed writing of right-handed individuals. That is, suggestions as to the purpose of the investigation were as carefully avoided, the tests were

similar, and reversals were as easily elicited as in the average right-handed subject. I found greater average difficulty in getting a right-handed reversal in those who had in the past practiced somewhat with the right hand. This I attribute to the fact that it is relatively a more automatic process for them to write rightwards with the right hand, due to the practice they have received in this action. Carrying this division to its extreme, we have those who have learned to write correctly with the left hand, but have subsequently been "broken" and trained in the use of the right hand. They are especially unlikely to give any clear-cut, consistent, spontaneous reversals by either hand. It seems not improbable that these individuals have developed two writing-centers, one for rightward left-handed writing which, according to my argument, would lead to right-handed mirror-writing; and one for rightward right-handed writing. Such a case is given by Acker[1]—a boy of ten years, broken of left-handedness, who wrote with equal facility in four different ways, viz.: mirror-writing with either hand and rightward writing with either hand. I experimented on two left-handed children who were being "broken" and found it an easy matter to develop them into similar cases.

Let us consider also those instances where there is a permanent injury to the right arm, and an acquired facility in rightward left-handed writing. The writing is at first a slow, labored, attentively controlled "drawing", typical of the ordinary left-handed attempt at writing. But this improves rapidly, and the writing comes to have much of the automatism characteristic of ordinary right-hand writing; yet is seldom, if ever, as completely automatic. Separate "centre" for mirror-writing is hence superfluous, and is probably not formed, although an additional centre for left-handed left-to-right writing—requiring as it would an entirely new set of kinesthetic responses—may presumably be formed by practice.

4. Recapitulation

My argument may be summarized as follows:

Mirror-writing depends upon two conditions. The one is the physiological element which embraces (a) the same single grapho-motor memory centre for written symbols that is employed for ordinary right-handed writing, and (b) the identical sensory-motor relation that left-handed reversed writing bears to right-handed rightward writing. Hence there is a predisposition towards unpracticed left-handed mirror-writing which exists coextensively with the ability to write with the right hand. There exists no such complex for left-handed centripetal writing. Mirror-writing is a relatively rare phenomenon. Therefore, it must depend upon the *disturbance* of some part of the writing apparatus other than the motor; for the integrity of the grapho-motor centre and the commisural paths is the very foundation upon which mirror-writing is based. This is the second condition, the psychological element. The psychological governor which supervises our ordinary writing, must be so rearranged or altered that the psysiological provision for mirror-writing is given an opportunity to act, or, perhaps, is encouraged or stimulated to independent action.

The most striking generalization to be drawn from observations on mirror-writing is that even in the most favorable conditions for mirror-writing there is a great deal of individual variation; that is, in any condition, such as hypnosis, one subject will write entirely mirrorwise, while another can scarcely be induced to write at all in this style. I find exactly the same relation in the description of those cases which occur spontaneously. The pathological conditions mentioned on pp. 201-202 are relatively common. Yet mirror-writing is so rare as to cause immediate comment whenever it occurs. This may be due to the fact that only infrequently do these patients attempt to use the left hand for writing, in which case mirror-writing could be expected in every instance when these patients were asked to use the left hand. Or, it may be that there is some

particular disorganization which occurs inconstantly in all of the conditions favorable to mirror-writing. And this in truth more nearly approaches the conditions which my own theory emphasizes. The more that the psychological, or higher, parts of the nervous system are disorganized, the more confidently may we expect a left-handed reversed writing to result. Again, the disorganization must be great enough to pass a certain minimal limit before one may expect spontaneous, complete left-handed reversals. And more particularly, we may expect that if the disorganization is of a specialized kind, one that will dissociate the automatic from the sensory and attentive control of the muscles, or, a step more, divert writing activity to the physiological element, the dissociation need be much less than if the disorganization is general. This is observed particularly when considering the relatively circumscribed disturbance occasioned by the majority of my experiments,* as against the great disorder of many of the pathological states in which mirror-writing occurs, notably the insanities.

There are two additional forms of left-handed mirror-writing —viz., the deliberate, intentional, attentive and the fragmentary. These also depend, but to a much less degree, upon the crossing of the secondary impulse. In the first of these forms, the less conscious or intentional the mirror-writing is, the greater is this dependence. Conversely, the more attention we devote to these movements, which are a new experience to our higher consciousness, the more dependence is placed upon the visuo-psychic and association areas for guidance. In the second type, there is a tendency for some reagents to make fragmentary reversals with the left hand, which depend to some extent upon the commissural paths, but as the reversals are, with lower grades of experience, frequent with the right hand, the ultimate explanation is found in the confusion of lateral relationships. This type can not properly be considered as a representative of true mirror-writing.

*See pp. 215 ff.

PART IV

RELATION OF CONCLUSIONS TO EARLIER EXPLANATIONS

Referring to the classification of previous hypotheses as given on page 214 I find that while the definitions of the occurrence of certain tendencies in movements are perhaps true, Group A does not comprehend the fundamental reason for mirror-writing. Of this group, the observations of Durand and Peckham strike nearest to the real cause of *mirror-writing,* in that they introduce quite prominently the factor of attention; Peckham including as well a physiological basis for the phenomenon.

The criticism of Groups B and C are several, and may be best made clear by referring to the observations which seem to favor the hypothesis of a single centre,* and in addition to the criticisms of Hale and Kuh† and of Sweeney‡ I have shown that it is possible to escape from the wholly unsatisfactory idea of the presence of a definite mirror-writing centre; and that the theory, rather than suffering from this omission, is actually rendered the stronger. The study of these groups brings out a matter of even greater moment, namely, that the physiological aspect of mirror-writing, however it be answered, is but a minor part of the solution of the question.

With the observations classed as group D, I agree. However, the same criticism as was made of group A applies here—the explanation is not sufficiently comprehensive. In every case of true mirror-writing (which it should be remembered, does not include reversals by the hand accustomed to writing) there must be a disturbance, a deflection, of the mental content, a dissociation of attention.

Group E, in placing prominence upon a factor of visual imagery, neglects the proper significance of the normal physiological, or grapho-motor, element as being the fundamental

*See pp. 227-237, also group D, pp. 210-211.
†See pp. 211-212.
‡See pp. 212-213.

means by which true mirror-writing is accomplished. I agree with the conclusion of Hale and Kuh on fragmentary right-handed reversals, but do not class this type as a representative of true mirror-writing. I cannot agree with their, or with Sweeney's answer to the question, why mirror-writing is not inverted: though their observations are sound, and are sufficient to account for right-handed reversals, yet the motor relations as I have described them would not permit of true inverted writing.

I agree with Downey in group F, that there is a motor as well as a visual representation of a movement. My experience has been that the majority of subjects, when voluntarily reversing their writing, exercise their attention principally to force the writing in a *reversed* direction. The actual reversal of the letters is by the guidance of the grapho-motor system. Attentive guidance is required only when a confusing or relatively unfamiliar letter brings uncertainty to the automatic control.

Many of the earlier explanations seem to be devised in view of the special conditions offered by some particular case of mirror-writing. Explanations of different observers have therefore differed widely. I have shown that all the reported causes of mirror-writing, or conditions favoring it* have characteristics in common. Further, I have shown that typical mirror-writings can be controlled by experimental methods, and that to study mirror-writing we do not need to seek the spontaneously occurring cases, as has been done in the great majority of reports. Lastly, I have shown that mirror-writing is a simple, direct and unified process, not at all as complicated and disconnected as a comparison of the several findings would lead one to expect. Its explanation is simply that certain impulses which do not ordinarily function, are by the conditions in which mirror-writing occur allowed to do so. These conditions, instead of being a more or less unconnected set of symptoms as indicated on pp. 201-202, I have shown to rest, with the experimental conditions, upon the common basis of dissociation.

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*See pp. 201-202.

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